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(54) Method and apparatus for the mixing of at least two fluid flows

(57) Apparatus for mixing at least two flows (Q_1, Q_2) includes a respective vortex-generating element (3) which is disposed at an acute angle to the direction of at least one of the flows, the element causing vortices at break-away edges so that the flows are thoroughly mixed. As shown, an element is disposed in one flow at each junction of two flows. Two elements in close proximity may be used. The elements may be used for various flow junctions, including coaxial flows. The elements may be triangular or other shapes. Alternatively, lateral flows (2) may have tubes (4) extending into a main flow to create the vortices. The tubes may take a variety of cross-sectional shapes.

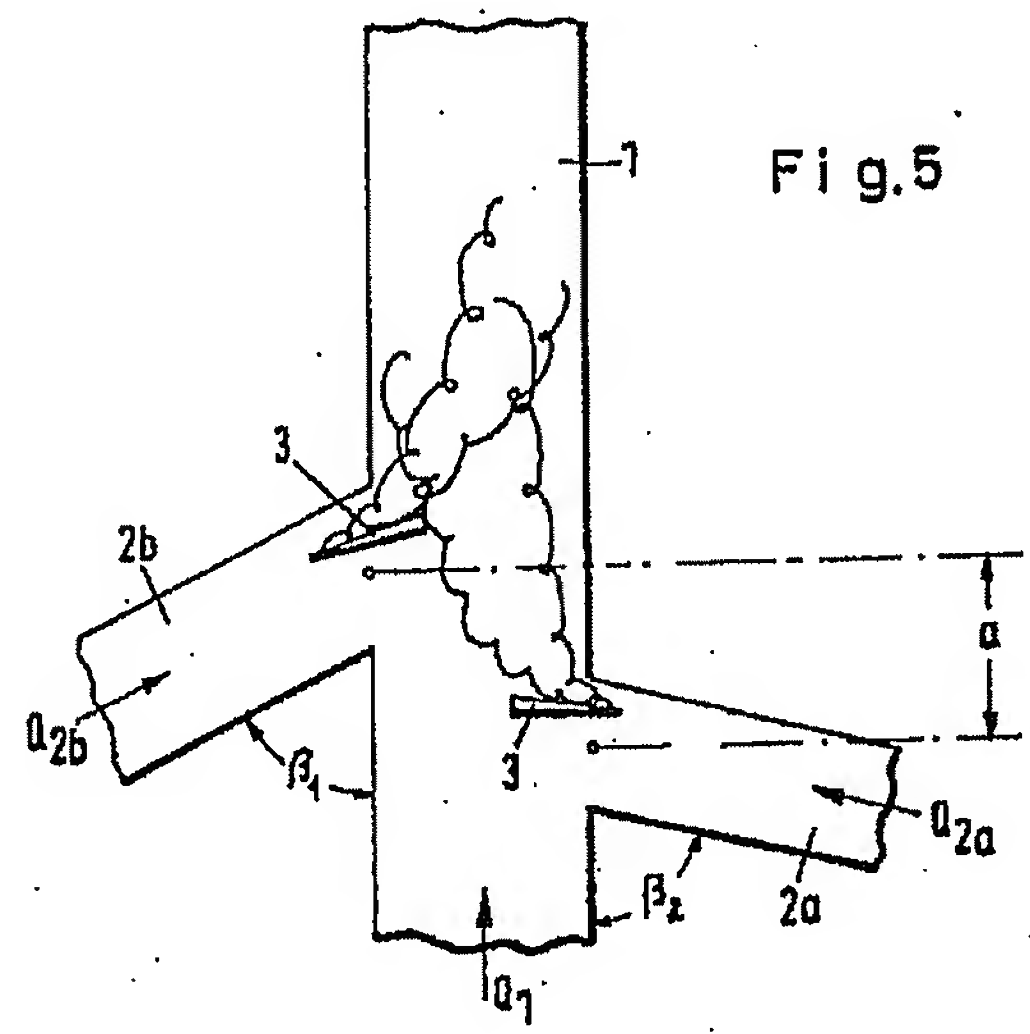

Fig.5

Fig.16

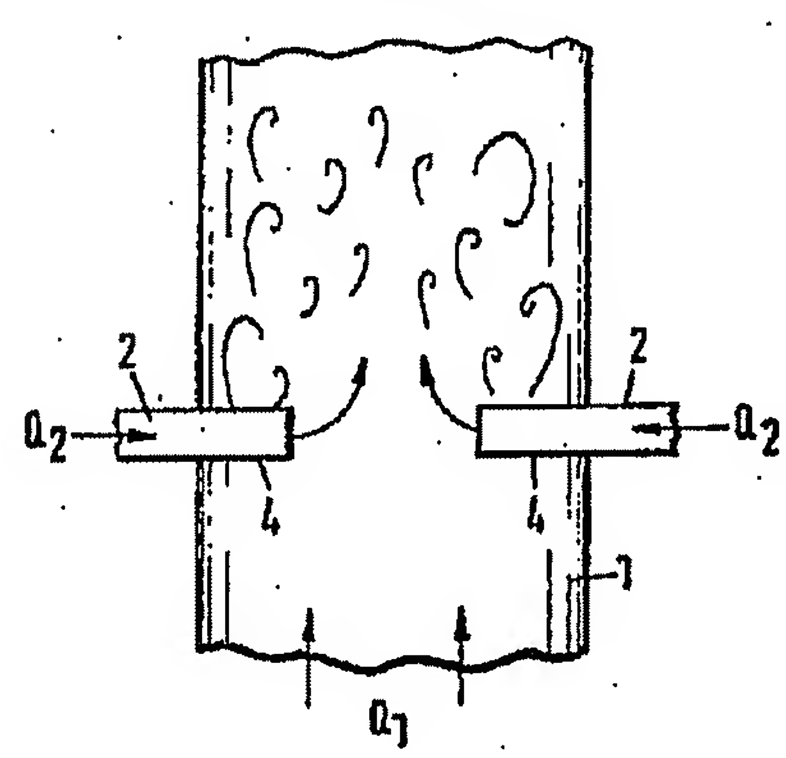

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Fig.1

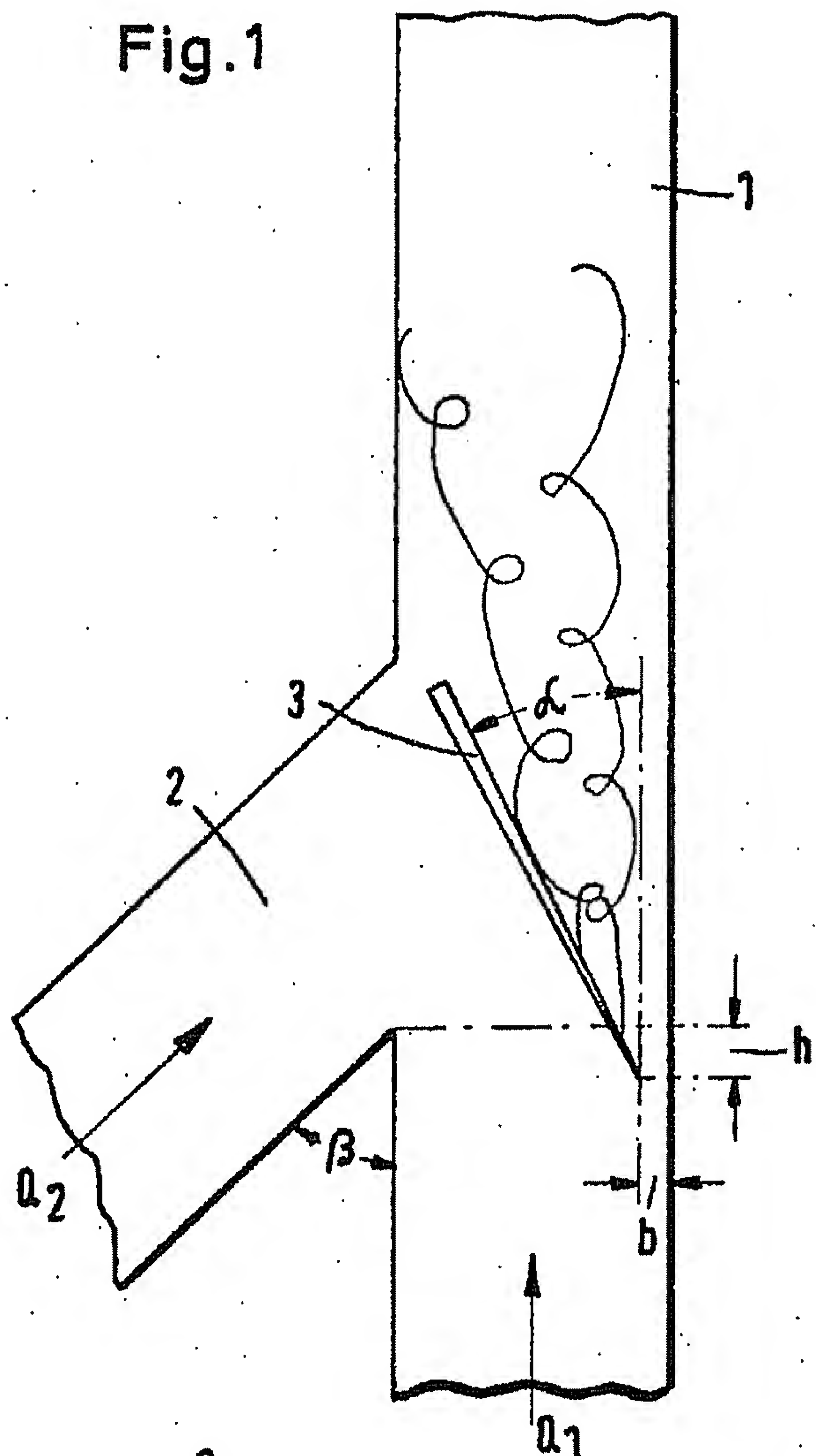
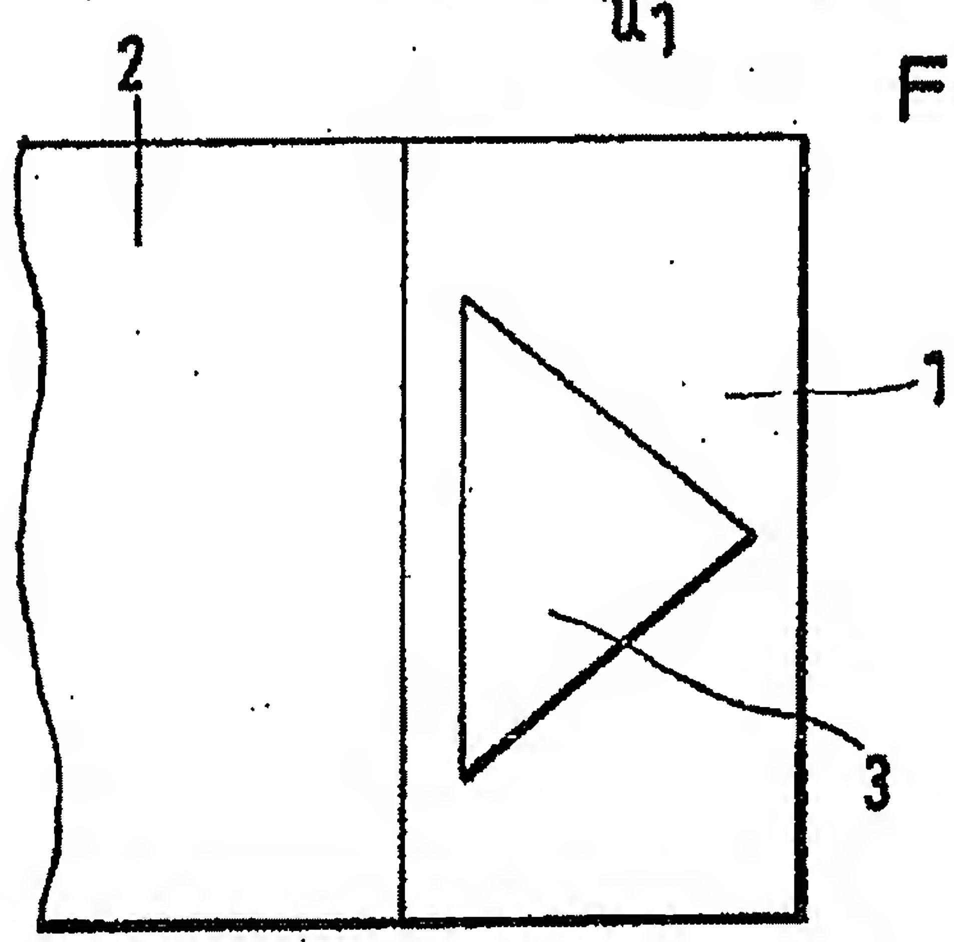


Fig.2



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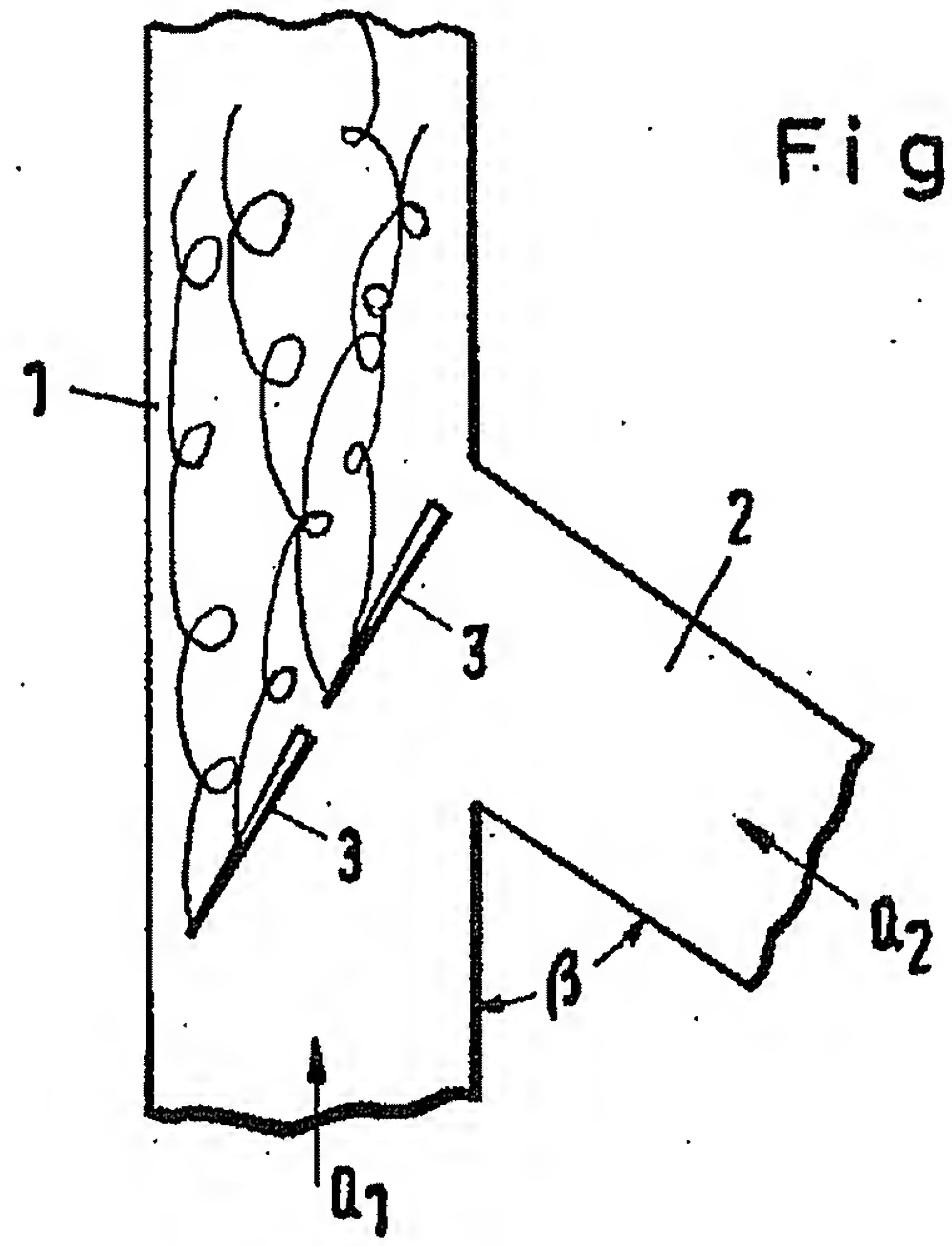
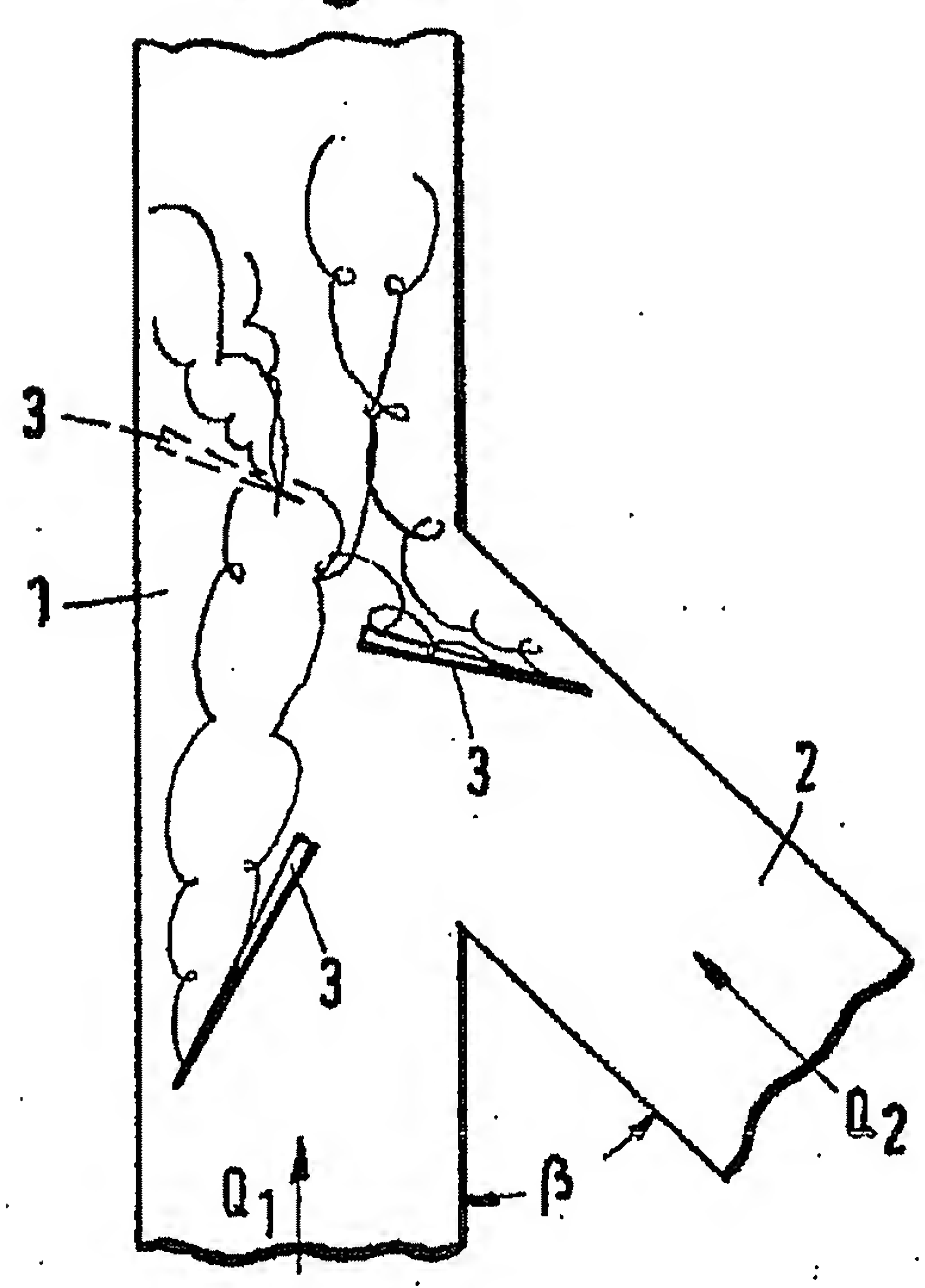


Fig.3

Fig.4



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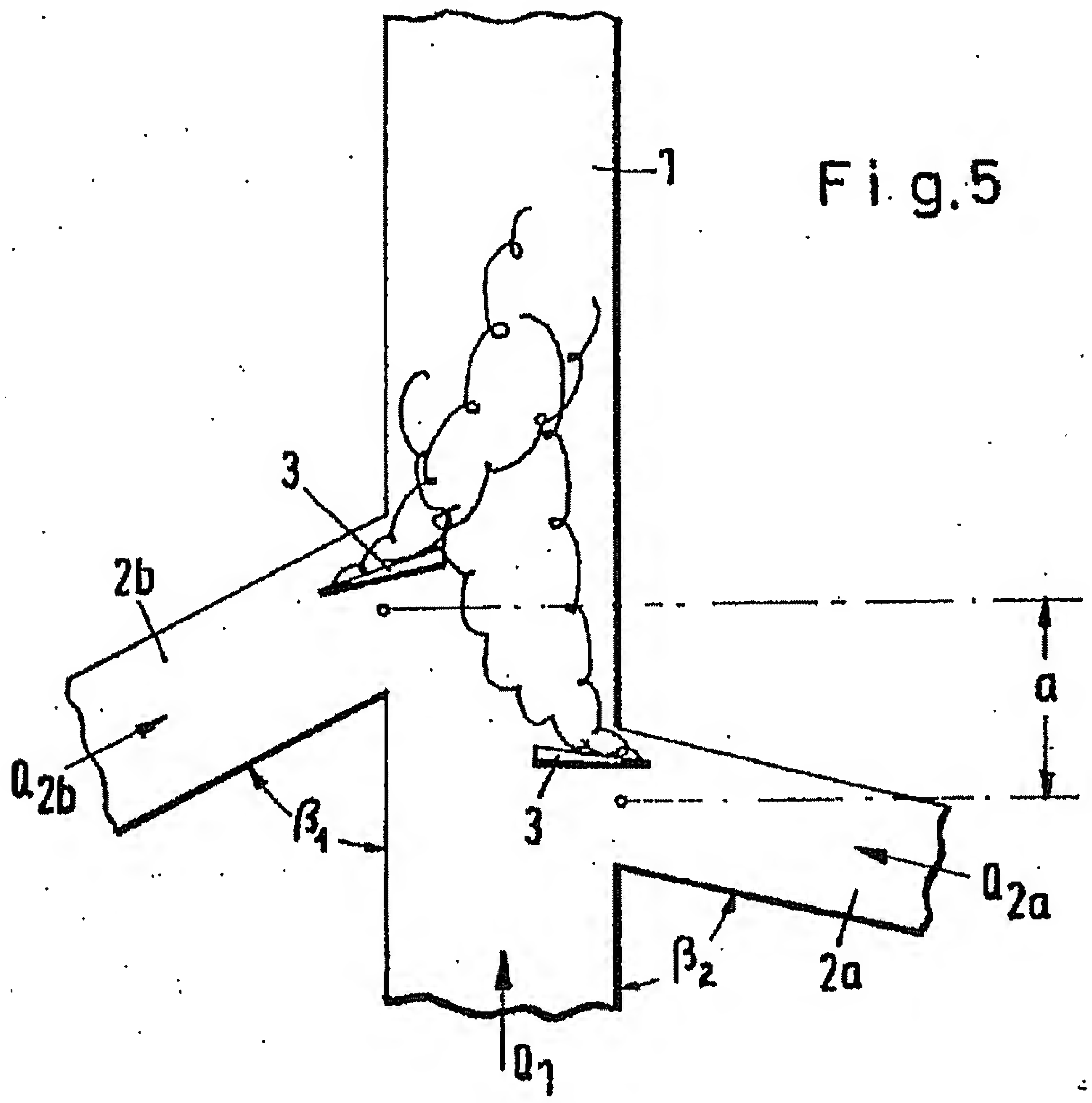

Fig.5

Fig.6

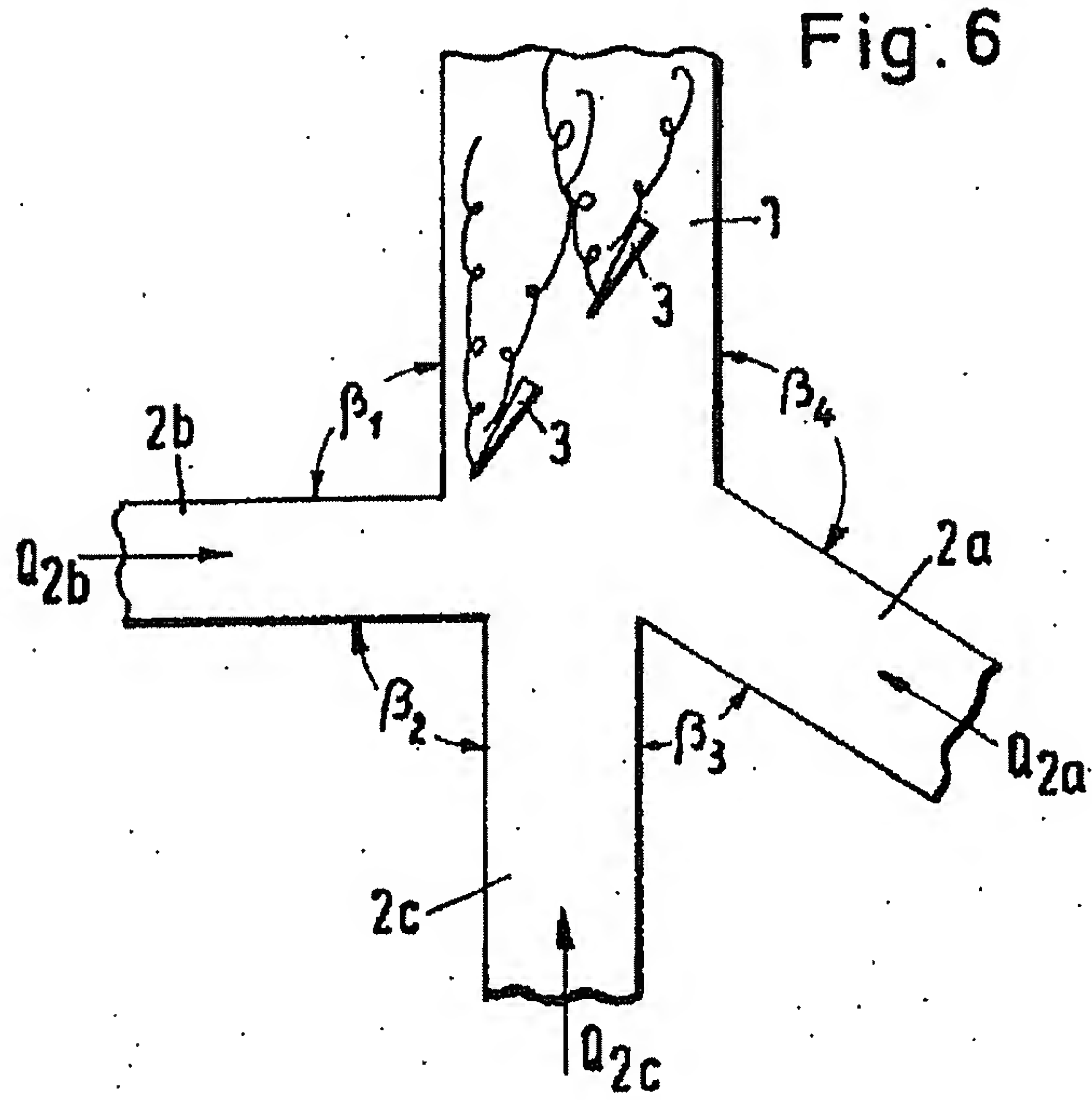

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Fig. 7

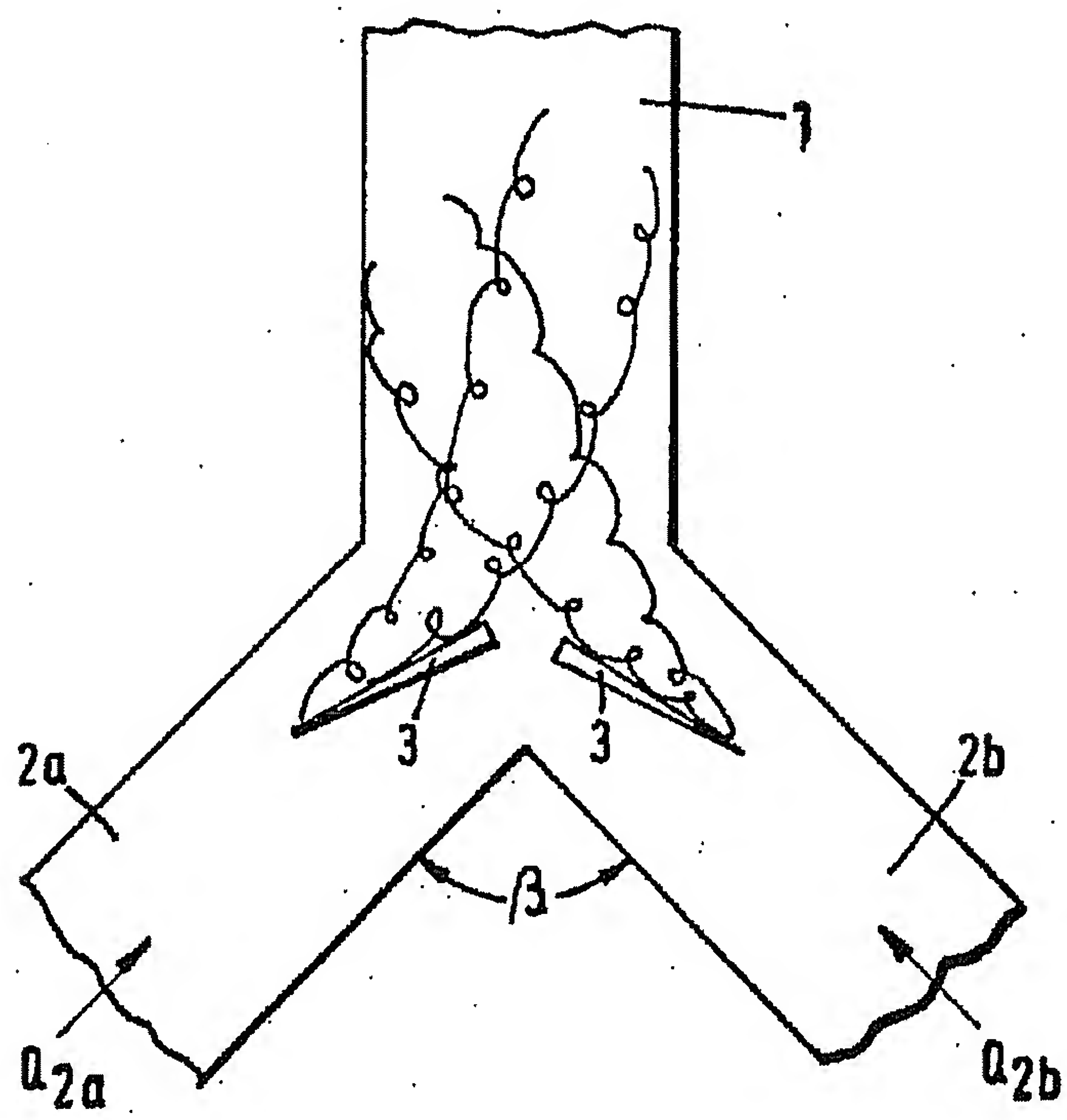

Fig. 8

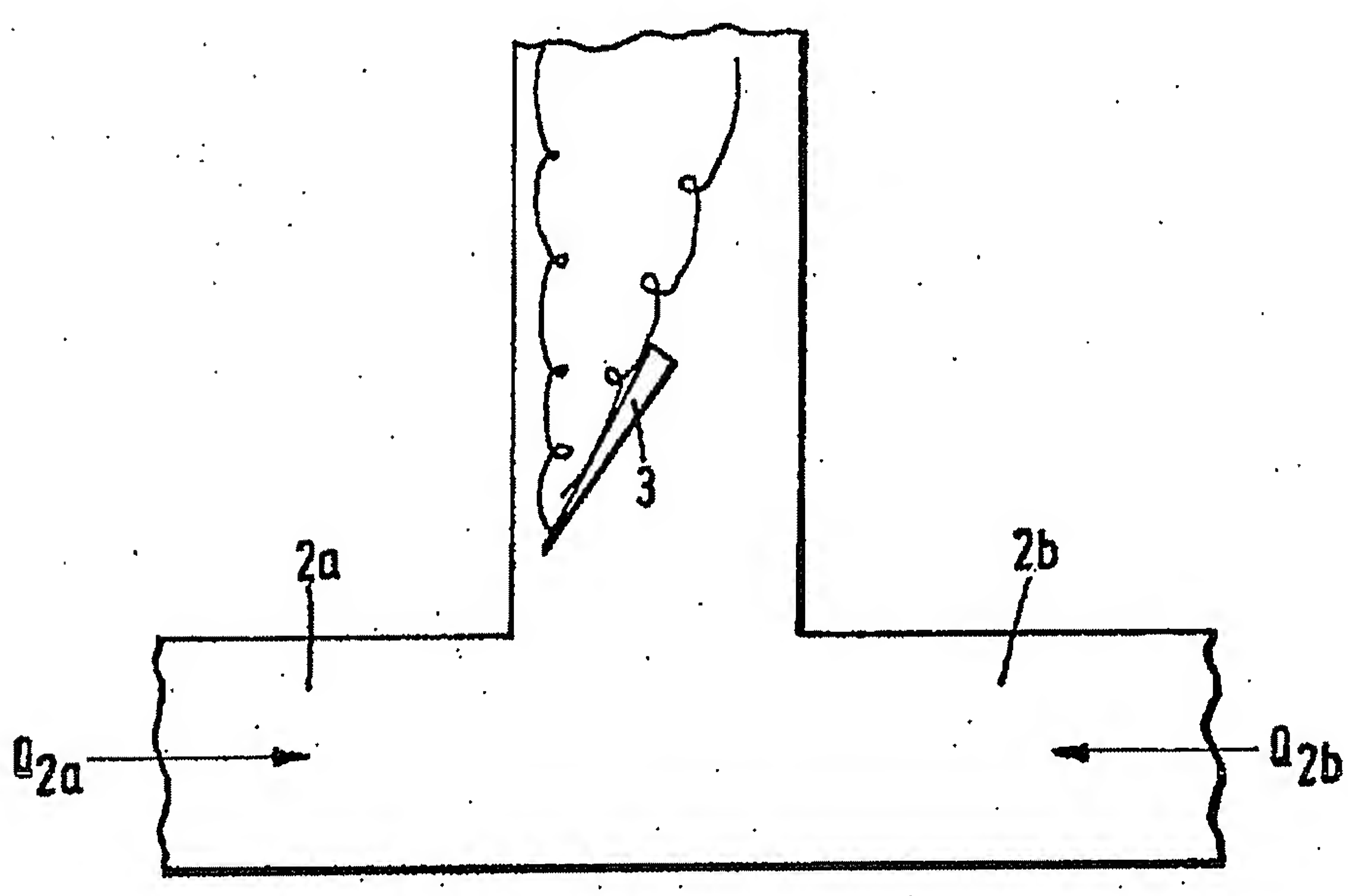

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Fig.9

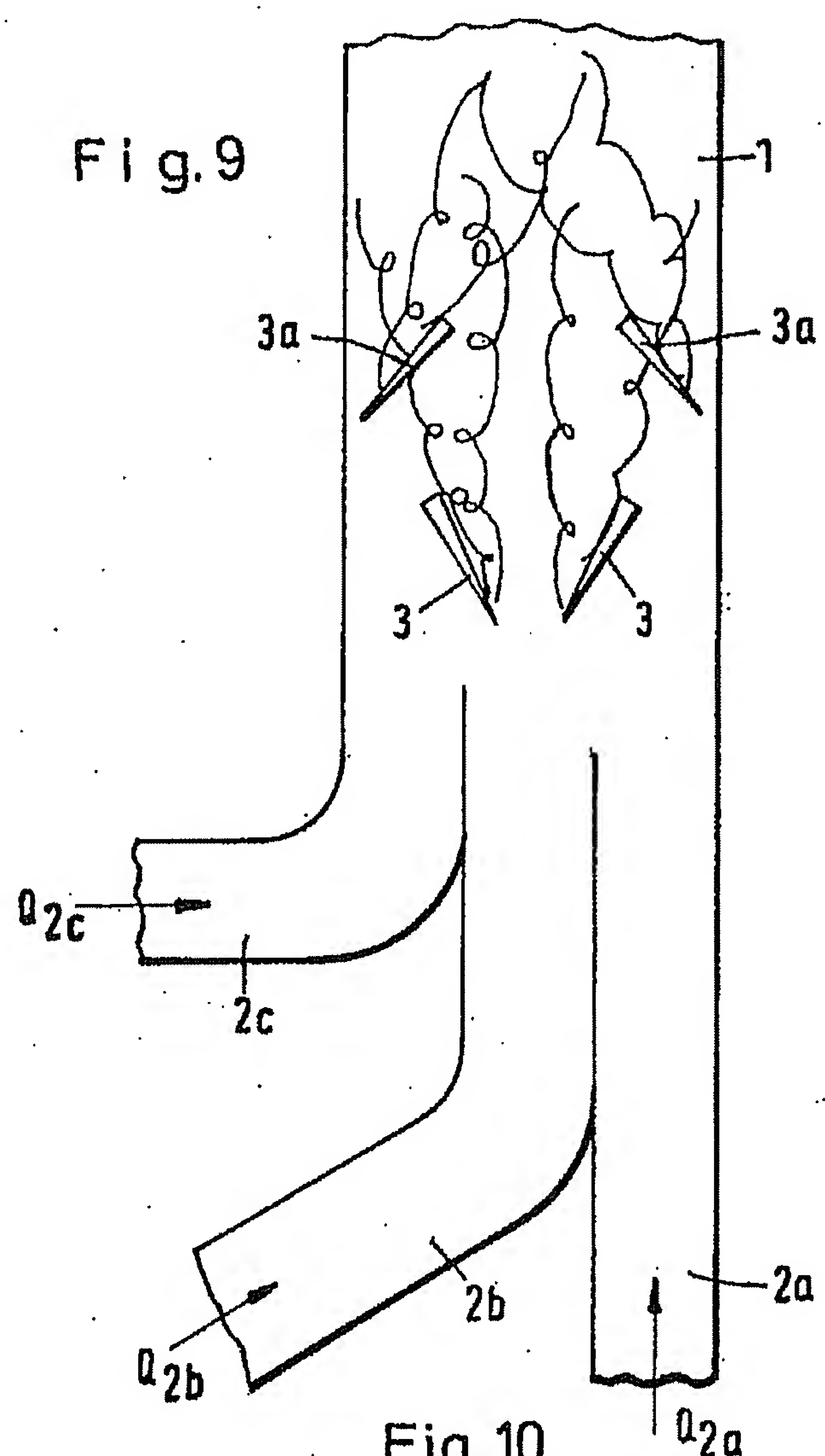

Fig.10

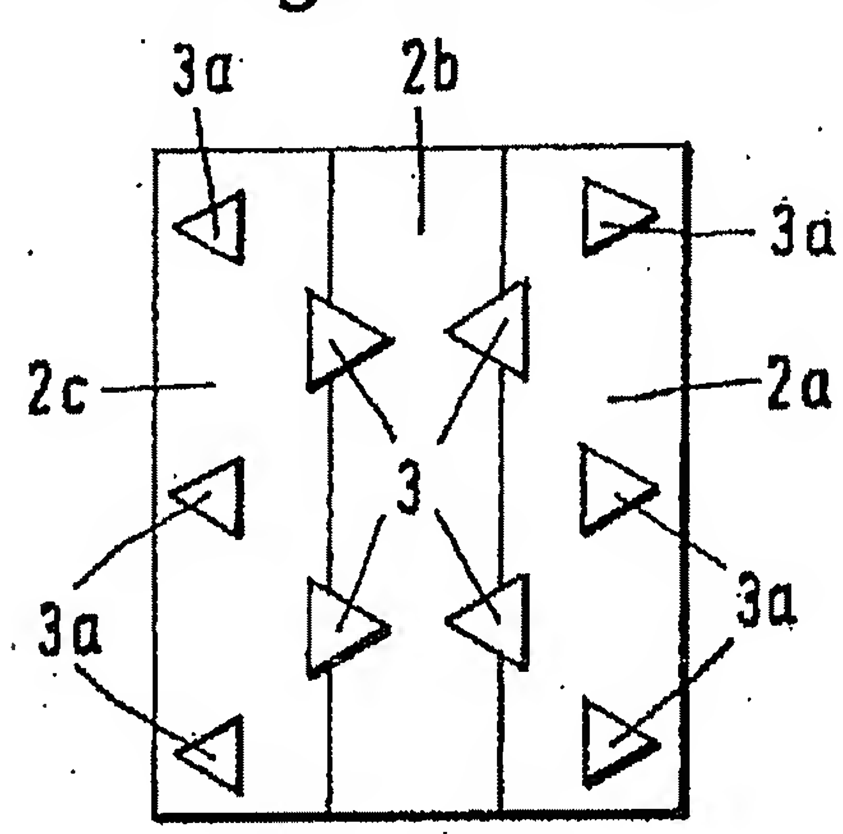

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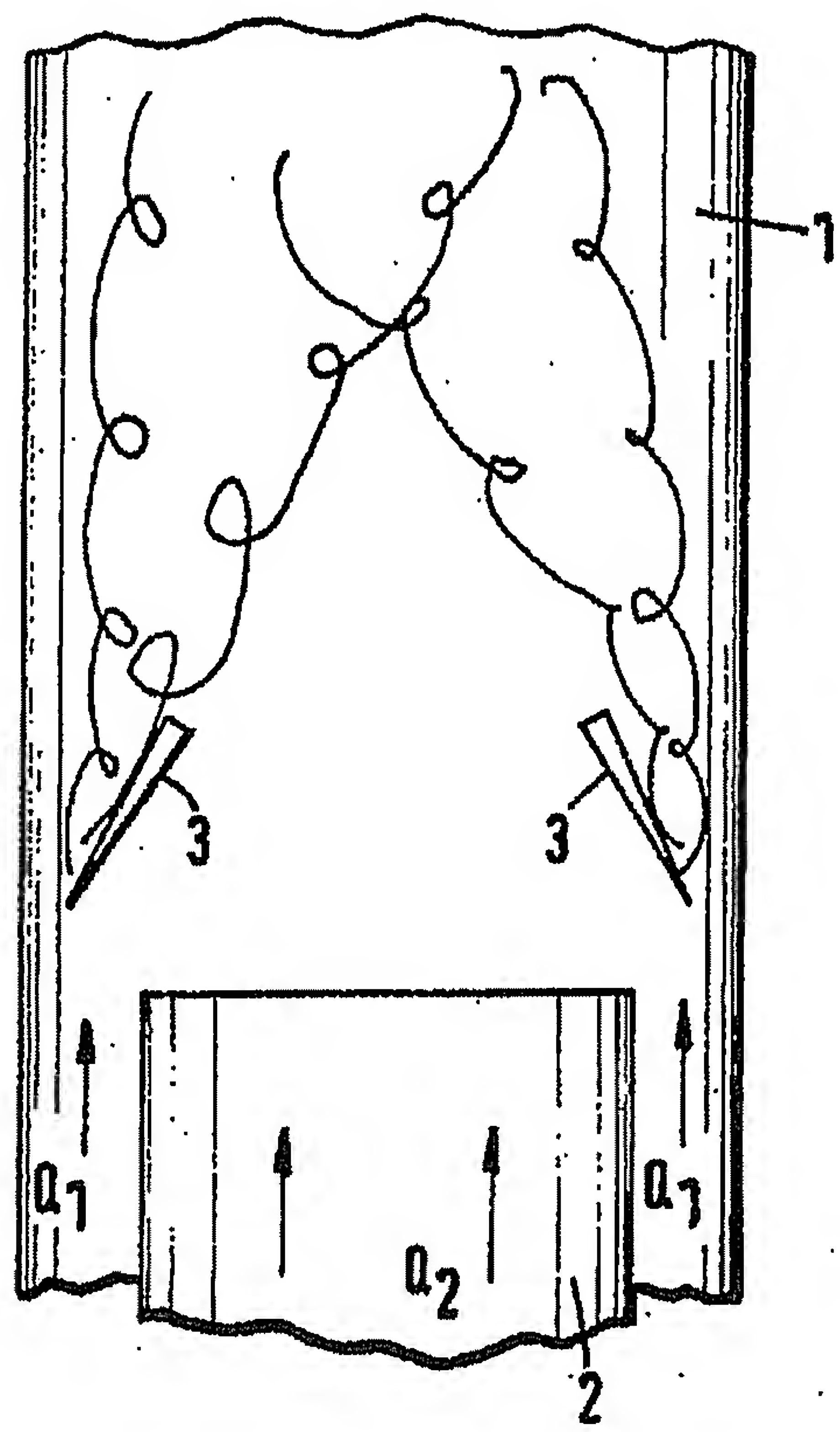
Fig. 11



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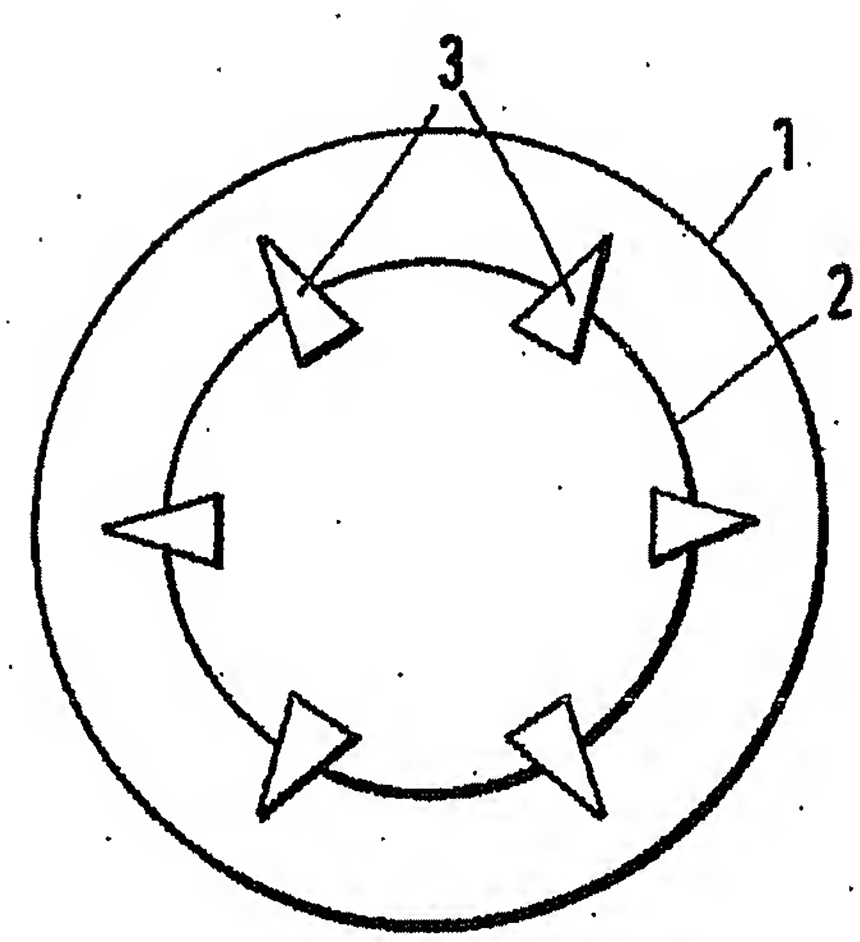

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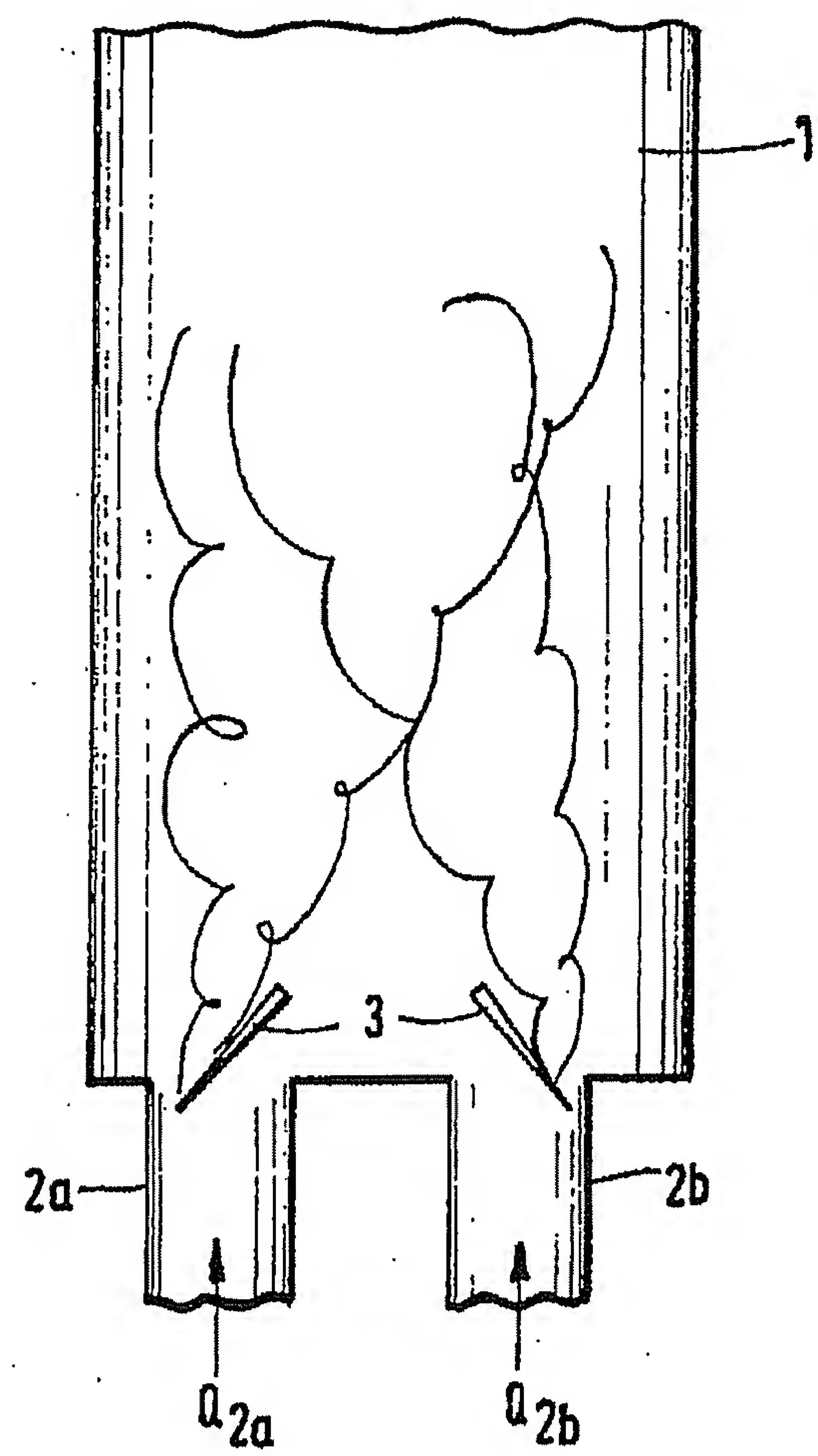

Fig.13

Fig.14

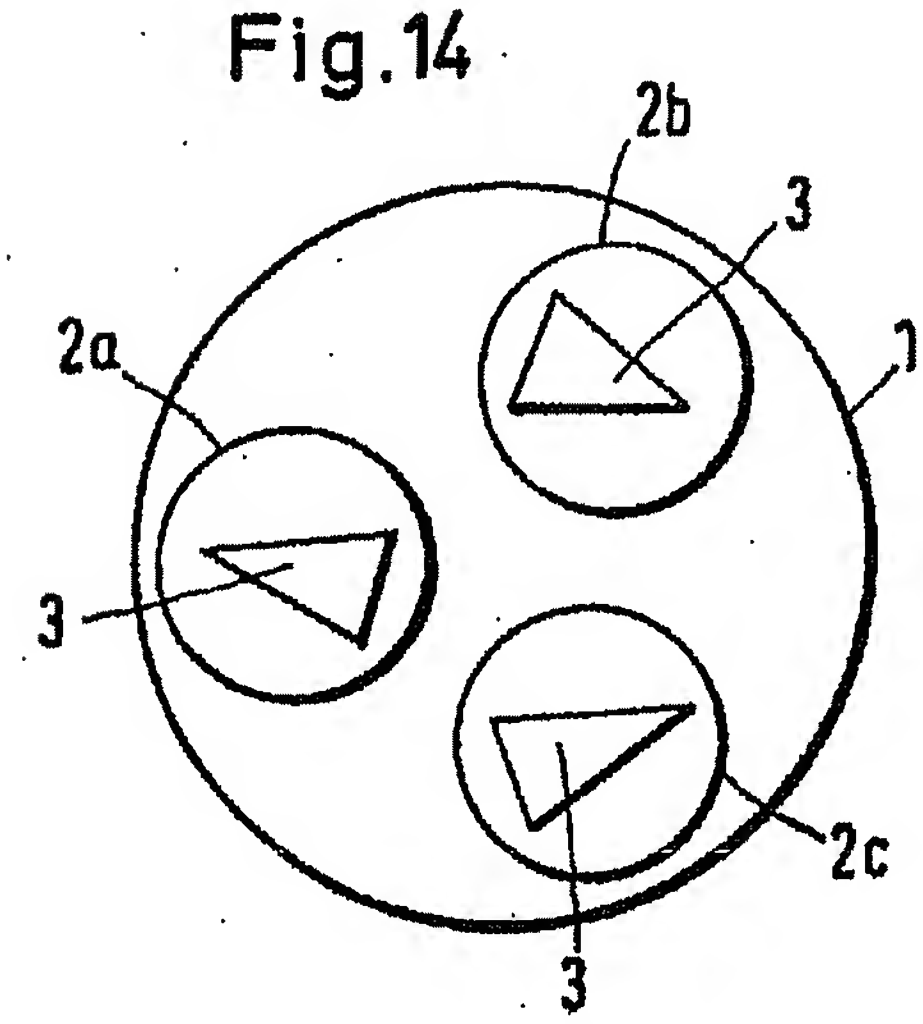

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Fig.15

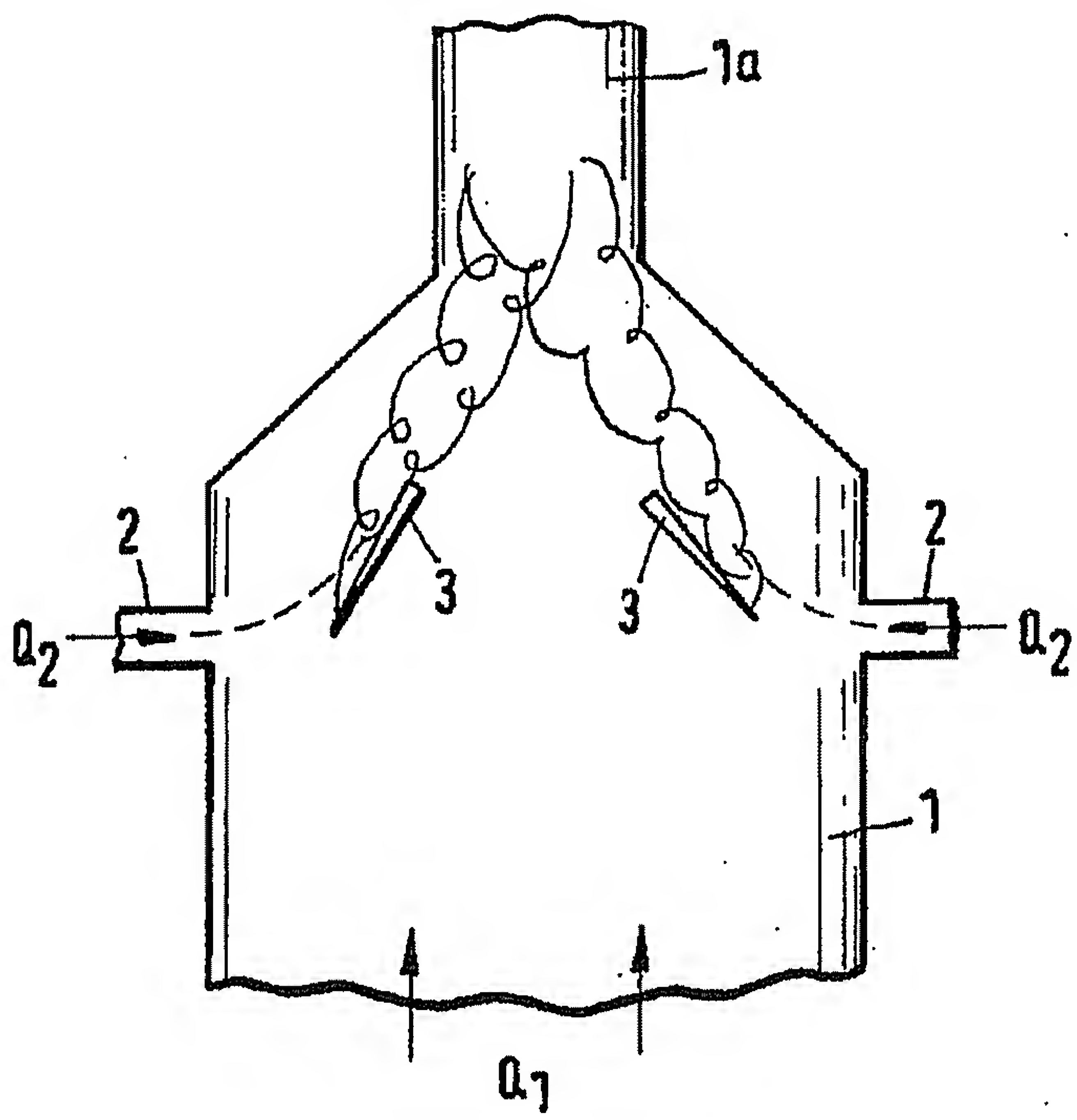


Fig.19

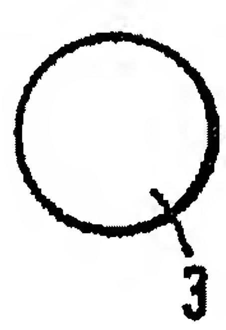
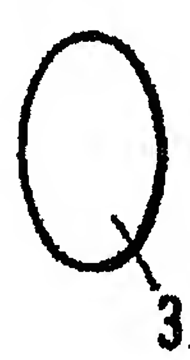


Fig.20



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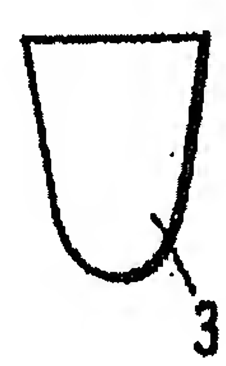

Fig.22

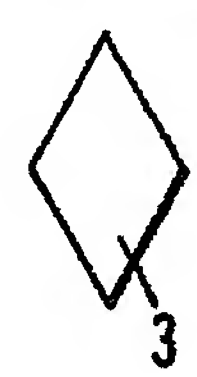

Fig.23

Fig.24

Fig.25

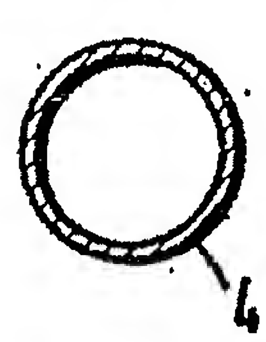

Fig.26

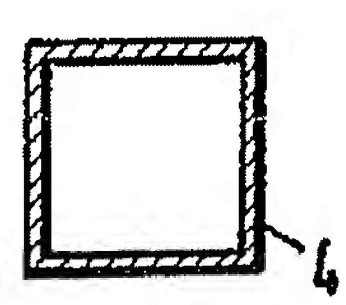

Fig.27

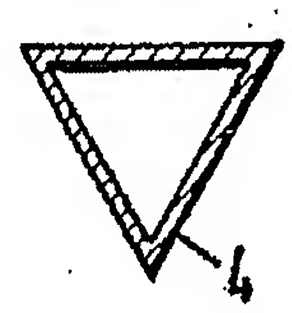

Fig.28

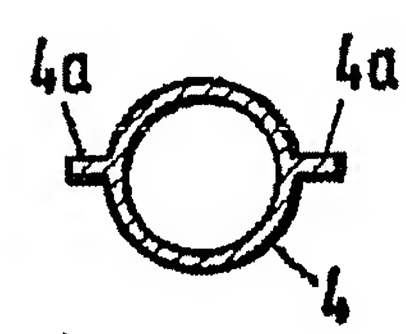

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Fig.16

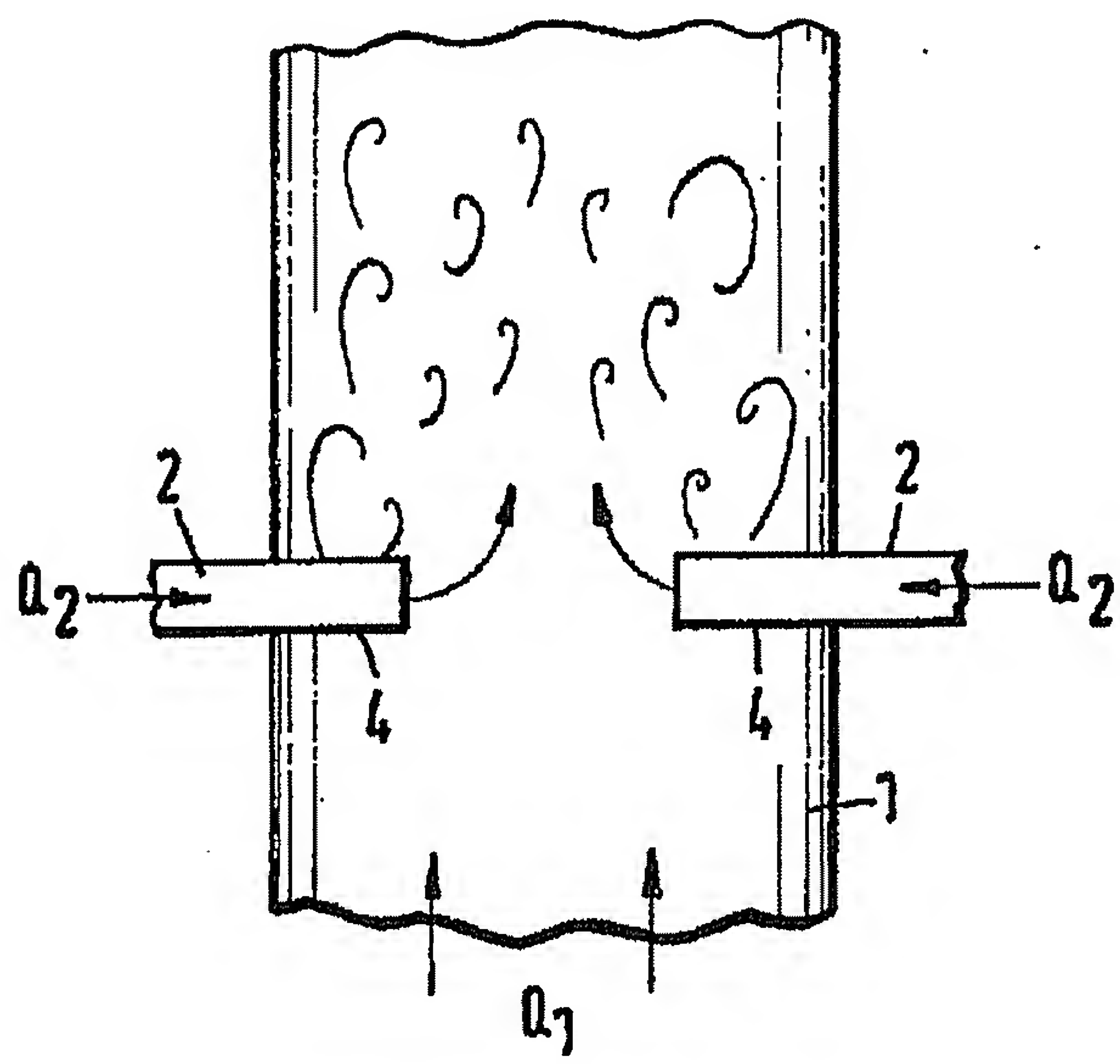

Fig.17

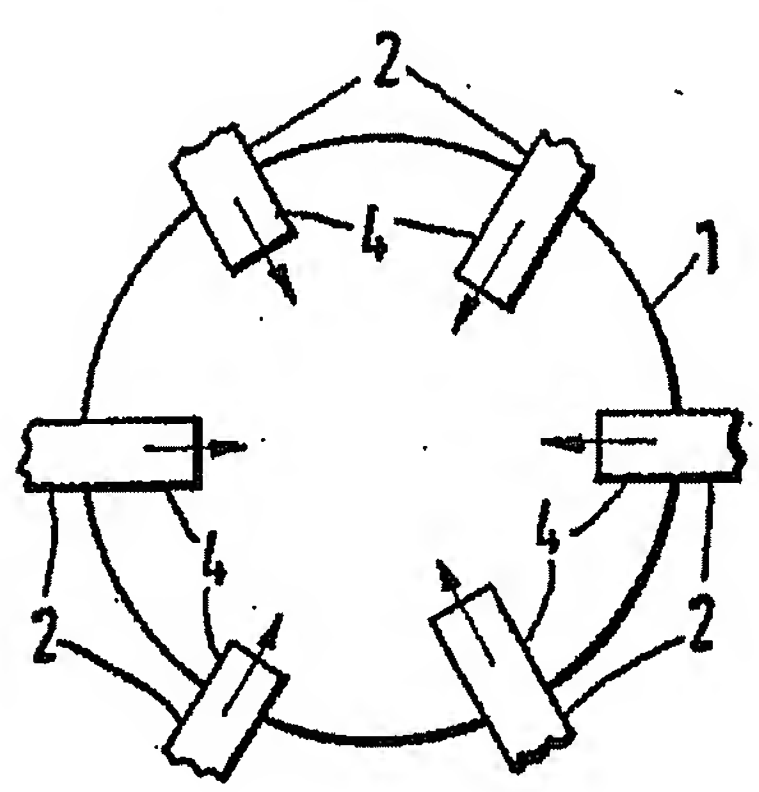

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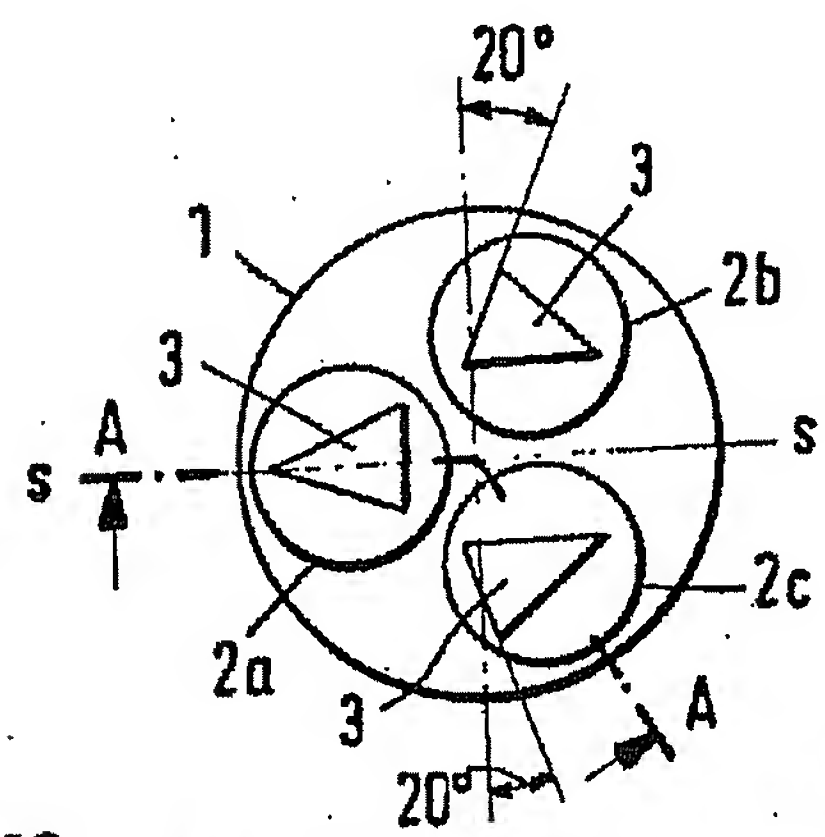
Fig. 18b

Fig.18a



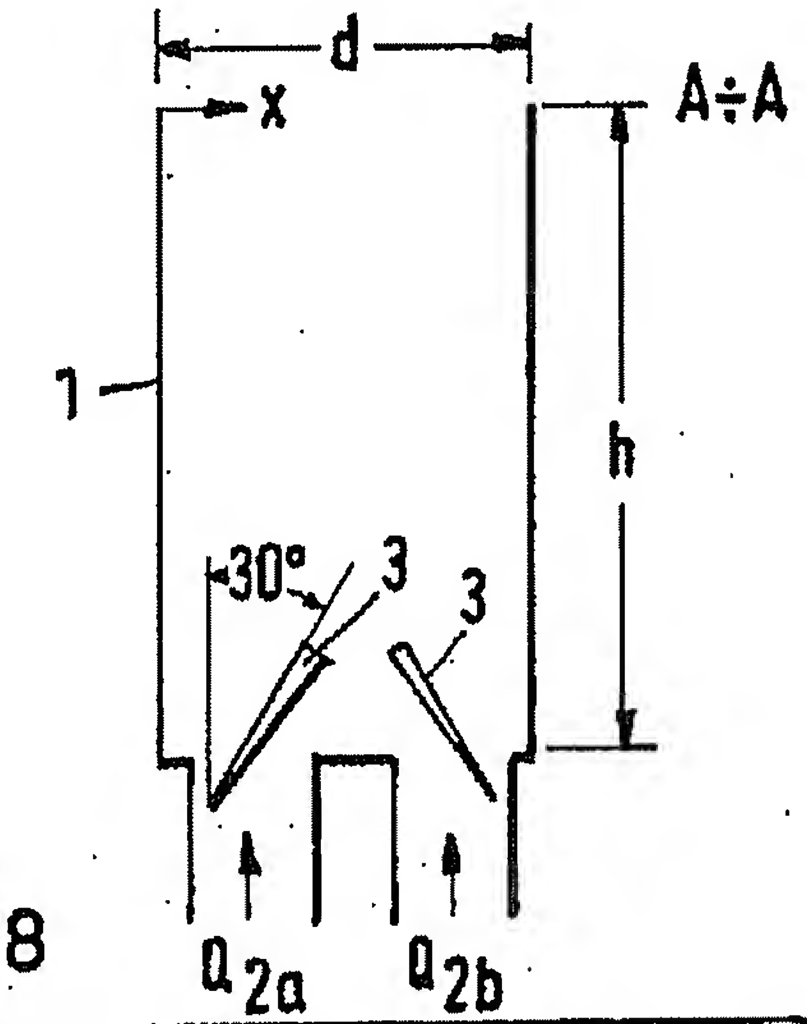
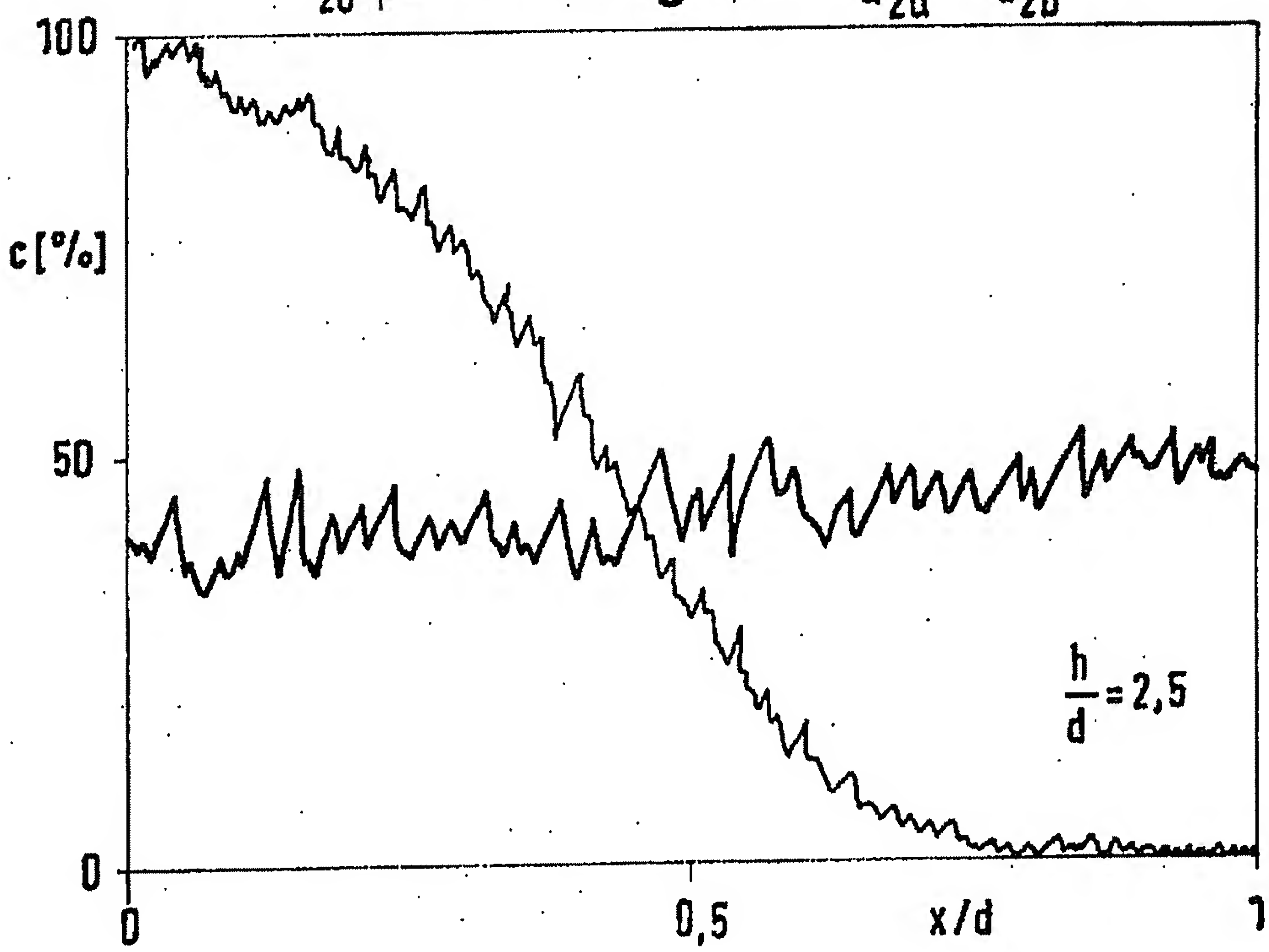


Fig.18



SPECIFICATION

Method and apparatus for the mixing of at least two fluid flows

This invention relates to a method for the mixing of at least two fluid flows and to apparatus for carrying out the method.

According to the present invention, there is provided a method of mixing at least two fluid flows comprising the steps of generating within at least one fluid flow at least one vortex, which widens downstream transversely to the flow direction to form a discrete vortex system, of which components transverse to the flow direction overlap into the flow cross-section of the other part flow whereby to effect the desired mixing.

Further according to the present invention there is provided apparatus for mixing at least two fluid flows comprising at least two ducts joining one another and a vortex-generating element mounted at or adjacent the junction and so disposed in relation to one fluid flow path that, in operation, a discrete vortex system is generated which penetrates into the other flow path whereby to effect the required mixing.

Apparatus for mixing fluid flows embodying the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a longitudinal section through a first embodiment with a continuous main duct and a supply duct connected at an acute angle thereto;

Figure 2 is a plan view of the apparatus according to Figure 1;

Figure 3 is a longitudinal section through a second embodiment;

Figure 4 is a longitudinal section through a third embodiment with a continuous main duct and a supply duct connected laterally thereto at an acute angle;

Figure 5 is a longitudinal section of a fourth embodiment, in which there are connected to a continuous main duct two lateral supply ducts offset longitudinally in relation to one another but both at acute angles;

Figure 6 is a longitudinal section through a main duct of a fifth embodiment, to which are connected three supply ducts at various angles;

Figure 7 is a longitudinal section through a main duct of a sixth embodiment, which is connected to two symmetrically arranged supply ducts, each at an acute angle to the length direction of the main duct;

Figure 8 is a longitudinal section of a seventh embodiment, in which two opposed supply ducts deliver into a rectangular, upstanding, main duct;

Figure 9 is a longitudinal section through a main duct of an eighth embodiment, in which a continuous flow cross-section is formed from three rectangular supply ducts initially extending at various angles to one another;

Figure 10 is a plan of the main duct to Figure 9;

Figure 11 is a longitudinal section through a main duct of a ninth embodiment, which is formed without change in cross-section by two supply ducts extending concentrically in relation to one another;

Figure 12 is a plan view of the main duct of Figure 11;

Figure 13 is a longitudinal section through the lower part of a main duct of a tenth embodiment with circular cross-section, into which three supply ducts deliver likewise with circular cross-section but, however, each with a smaller cross-sectional area;

Figure 14 is a plan view of the main duct of Figure 13;

Figure 15 is a longitudinal section of a main duct of an eleventh embodiment with a tapering cross-section and with several laterally connected supply ducts;

Figure 16 is a longitudinal section of a main duct of a twelth embodiment with circular cross-section to which are connected six supply ducts with any appropriate cross-section, with the tube sections projecting into the main duct;

Figure 17 is a plan view of the main duct of Figure 16;

Figure 18 is a diagram of a test model plotting smoke concentration, measured at the height h at the diameter s - s of a model, which is illustrated in plan view in Figure 18a and in longitudinal section in Figure 8b;

Figures 19 to *22* have plans of four different basic shapes of an insert element forming parts of each of the hereinbefore mentioned embodiments;

Figures 23 and *24* are respective cross-sections through two insert elements; and

Figures 25 to *28* are cross-sections through four tubular insert elements such as illustrated in Figures 16 and 17.

The first embodiment illustrated in Figures 1 and 2 shows a main duct 1 of rectangular cross-section, to which is connected a supply duct 2 at a junction angle β. A part flow Q_1 flows in the main duct 1, which receives a part flow Q_2 from the supply duct 2.

A delta-shaped insert element 3 is mounted in the delivery region of the supply duct 2, which is adjustable through the adjustment angle α in relation to the flow direction of the part flow Q_1 and has its point opposed to the flow direction. The tip of the insert element 3 is at a distance *b* from the continuous wall of the main duct 1 and extends in relation to the lower edge of the supply duct 2 with an immersed depth *h* into the main duct 1 upstream of the delivery location.

The edges of the insert element extending symmetrically to the main flow direction, which have components extending both in the main flow direction as also transverse thereto, generate vortex impulses which widen downstream in the main duct transverse to the flow direction to form a discrete vortex system as is indicated diagrammatically in Figure 1. The components of this vortex system overlap transversely to the main flow direction of the part flow Q_1 into the flow cross-section of the part flow Q_2, so that an intensive intermixing of the part flows Q_1 and Q_2 is achieved downstream of the junction. The delta-shaped insert element 3 produces in this way no substantial reversal or deflection of the part flow Q_1, but achieves the intermixing by the hereinbefore described vortex system, which

prevents the two flow parts Q_1 and Q_2 from flowing adjacent, but without substantial mixing, to one another in the upper part of the main duct 1, as would be the case without the insert element 3. The insert element 3 extends with its upper edge comparatively far along the opening of the supply duct 2, in order also to generate in the part flow Q_2 a vortex impulse and to prevent the remaining part of the part flow Q_2 from remaining unmixed at the wall of the main duct 1 extending upwardly. The illustration shows that such a stratification is prevented by the vortex system widening out in the downstream direction.

In the second embodiment illustrated in Figure 3, once again a lateral supply duct 2 is connected at a junction angle β to a main duct 1. In this apparatus, however, two delta-shaped insert elements 3 are incorporated in the main duct, which tends to produce in the main duct 1 a vortex formation so that the part flow Q_2 provided from the supply duct 2 is intermixed intensively with the part flow Q_1 provided in the lower part by the main duct 1. The lower of the two insert elements 3 thus generates a substantial vortex impulse within the part flow Q_1 whereas the upper insert element generates a widening vortex system substantially in the part flow Q_2.

Also in the third embodiment of Figure 4, the supply duct 2 is connected at an acute junction angle β to the main duct 1. In the part flow Q_1 a vortex system is again generated by an insert element 3. Differing from the embodiment according to Figure 3 the vortex system is generated in the part flow Q_2 by an insert element 3, which projects partly into the supply duct and is adjusted in opposition to the upper insert element 3 according to Figure 3. With this embodiment a third, additional, insert element 3 has been mounted behind the opening of the supply duct 2 into the main duct 1, as this is indicated in broken lines in Figure 4. This additional insert element 3 effects by its additional vortex formation a shortening of the length required for mixing.

In the embodiment of Figure 5, two supply ducts 2a, 2b are connected to a continuous main duct 1, at a junction angle β_1 and respectively β_2 and offset by the amount *a* in the longitudinal direction of the main duct 1. In the delivery zone of each supply duct 2a,2b a delta-shaped insert element 3 is mounted, which generates the diagrammatically illustrated vortex system of Figure 5, which effects an intensive mixing of the part flows Q_{2a} and Q_{2b} in the part flow Q_1. The insert element 3 partially projects into the respective supply ducts 2a,2b so that the mixing length is shortened.

According to the fifth embodiment of Figure 6, it can be sufficient with a spaced connection of three supply ducts 2a,2b,2c to a main duct 1 at the same level, to arrange downstream of the delivery region several delta-shaped insert elements 3, which generate vortex systems extending over the whole cross-section of the main duct 1. In the embodiment, by way of example, according to Figure 6 the part flows Q_{2a}, Q_{2b} and Q_{2c} are mixed in the main duct 1, the supply ducts 2,2b,2c are connected at various connection angles to the main duct 1 and furthermore have differing flow cross-sections.

The sixth embodiment according to Figure 7 shows once again a main duct 1, which is formed by two acute angled and symmetrically connected supply ducts 2,2b through which the part flows Q_{2a} and respectively Q_{2b} are delivered to the main duct 1. In this embodiment, two delta-shaped insert elements 3 are mounted in the delivery zone of the supply ducts 2a and 2b, which generate intersecting vortex systems immediately downstream of the delivery zone and effect an intensive and thorough mixing of the part flows Q_{2a} and Q_{2b}.

The seventh embodiment of Figure 8 has two supply ducts 2a and 2b opposed to one another for the respective part flows Q_{2a} and Q_{2b}, which deliver into a main duct 1 extending at right angles thereto. To provide for thorough mixing of the part flows Q_{2a} and Q_{2b}, a delta-shaped insert element 3 is mounted in the main duct 1, which generates with its edges vortex systems which lead to a low-loss intermixing of the part flows Q_{2a} and Q_{2b}.

The eighth embodiment of Figues 9 and 10 has a main duct 1 formed from three supply ducts 2a,2b and 2c each with a rectangular cross-section, which deliver into the main duct parallel to and adjacent to one another; upstream, however, the supply ducts extend from different directions. In this embodiment several delta-shaped insert elements 3 are mounted in the boundary flow areas between adjacent part flows Q_{2a} and Q_{2b} or respectively Q_{2b} and Q_{2c}. These are, in longitudinal section, the lower and in the plan view the four intermediate insert elements 3. In order to assist the action of these insert elements 3 and to shorten the mixing length, in the embodiment of Figures 9 and 10 downstream of the said elements 3 mounted in the boundary flow area further insert elements 3a are mounted in the main duct 1, which are disposed in opposition to the flow direction at the lower insert elements 3 and the part flows Q_{2a} and Q_{2c} are provided with a more rapid mixing.

In place of the supply ducts delivering parallel to one another and adjacent to one another into the main duct 1 according to Figures 9 and 10, the supply of a part flow Q_1 to a part flow Q_2 according to the embodiment of Figures 11 and 12 can be effected also by concentric arrangement of the supply duct 2 in relation to the main duct 1. The delta-shaped insert elements 3 are arranged in the manner of a ring of the closed boundary flow surface and specifically are equally divided, as the plan view of Figure 12 indicates. The formation of the vortex system is indicated in Figure 11 whereas, in contrast, the rotationally symmetrical arrangement of the insert elements 3 is best apparent in Figure 12.

The embodiment of Figures 13 and 14 shows a main duct of circular form in cross-section, which may be the lower part of a chimney, into which from below three supply ducts (2a,2b,2c) deliver parallel to one another and each has a circular shape and the ducts are of equal sized flow cross-sections in relation to one another. The flow cross-section of the main duct 1 is larger than the sum of the flow cross-sections of the supply ducts 2a,2b,2c. In order to effect an intensive and thorough mixing of the part flows Q_{2a}, Q_{2b} and Q_{2c} within the main duct 1,

there is mounted in the delivery region of each supply duct 2a,2b,2c a delta-shaped insert element 3. The orientation of this insert element 3 in the delivery opening of the supply ducts 2a,2b,2c is determined in relation to the quantities of the part flows Q_{2a}, Q_{2b} and Q_{2c} at any given time.

A diagram of the smoke concentration of a test model of the embodiment of Figures 13 and 14 is shown as Figure 18. Figures 18a and 18b show various characteristic quantities for the test model, in which the part flow Q_{2a} with smoke would be made apparent, whereas in contrast the part flows without smoke Q_{2b} and Q_{2c} would be passed through the supply ducts 2b and 2c. The smoke concentration along the diameter s-s in Figure 18a would be measured with a measuring sensor, and specifically at the height *h*, which corresponds to 2.5 times the diameter of the main duct 1.

The substantially horizontally extending curve of the diagram of Figure 18 shows, that in spite of the eccentric introduction of the smoke through the supply duct 2a into the main duct 1, by means of the insert element 3 a complete and thorough mixing of the part flows Q_{2a}, Q_{2b} and Q_{2c} is achieved, the comparatively sharply formed crests and troughs of the substantially horizontally extending curve making it apparent that in the central plane local vortices have been formed by the delta-shaped elements 3. The S-shaped and diagonally extending curve in the diagram 18 gives again the condition without the insert elements 3. It is to be seen that in this case in the left part of the main duct 1 an almost 100% smoke concentration exists and specifically corresponds to the height H which is 2.5 times the diameter of the main duct 1. The effect achieved with the insert element 3 of low loss and intensive thorough mixing of the part flows Q_{2a}, Q_{2b} and Q_{2c} clearly demonstrates this with reference to the diagram according to Figure 18.

In the embodiment of Figure 15 the main duct tapers to an exhaust duct 1a downstream beyond the junction with the supply ducts 2, which have substantially smaller cross-sections than the main duct 1. In this embodiment in the region of each boundary flow surface indicated by broken lines there is mounted a respective insert element 3, so that vortex systems are generated, which extend in the direction towards the reduced section exhaust duct 1a.

While in the hereinbefore described embodiments the insert elements are constructed as delta-shaped surfaces with break-away edges, the embodiment according to Figures 16 to 17 shows the use of curved surfaces for the generation of the vortex pulses, which gives rise to a downstream discrete vortex system widening in a direction transversely to the flow direction. The illustration shows the main duct 1 of circular cross-section to which are connected six supply ducts 2 at right angles and each extending radially. The supply ducts 2 each project at a tube section 4 into the main duct 1. The curved surfaces of each tube section 4 serve for the generation of a discrete vortex system, which widens downstream and provides thorough mixing of the part flow Q_2 introduced through the supply ducts 2 with the part flow Q_1 of the main duct. The tube sections 4 may project into the main duct by amounts in the range 10% to 25% of the diameter of the main duct. The tube sections 4 can have, according to Figures 25 to 27, a circular, rectangular or triangular cross-section. Circular or oval tube sections 4 are preferably provided according to Figure 28 on their outer surfaces with preferably two sharp edged members 4a which serve as break-away edges and increase the impulse for the generation of the vortex system.

Finally four different embodiments of generally flat insert elements 3 are shown in Figures 19 to 22. These Figures show that in place of the hitherto explained delta-shaped construction, alternatively a circular, oval, parabolic, rhombic, or elliptical shape is possible. As shown in Figure 23 the insert element 3 can be made with the aim of increasing its stability of V-shape in cross-section. Furthermore, it is possible to provide the insert element 3 according to Figure 24 with angled edges 2b which on the one hand increase the stability and on the other hand tend to produce a substantially stronger vortex pulse.

The cross-section of both the supply ducts and the main duct of the hereinbefore described embodiments can be rounded (circular or oval), rectangular or any desired cross-section. Also the relationship of the flow cross-sections of the individual ducts to one another is selectable in any appropriate manner, so that in particular the cross-section of the supply ducts can be made with various values.

The method hereinbefore described can be used both for liquids as also for gases and is suitable in particular for solving various mixing problems for the mixing of flue gases, exhaust gases and smoke.

The various apparatus hereinbefore described effect not only an intensive intermixing over a short flow path and with low pressure losses, but are inexpensive, which opens up the possibility of incorporating the apparatus in already existing and installed ducts. Since the insert elements do not act to deflect or reverse flows but serve for the generation of impulses, they have an extremely low degree of obstruction and are unaffected by fouling.

The method hereinbefore described provides substantially better intermixing with approximately one half of the length of the mixing zone of conventional methods and a pressure loss of from 10 to 20% of the pressure loss of conventional methods. These advantages are believed to be achieved in essence in that neither driven mixing devices nor inserts causing large deflections and a high degree of obstruction are used, which positively deflect parts of the flow, but that by fixed insert elements with small degree of deflection there are generated vortex impulses, which by their downstream spreading transversely to the flow direction cause a low loss intermixing of the part flows, since the components of the vortex system in the flow cross-section extending transversely to the main flow direction overlap the other part flow and cause in this manner an intensive intermixing.

CLAIMS

1. A method of mixing at least two fluid flows comprising the steps of generating within at least one fluid flow at least one vortex, which widens downstream transversely to the flow direction to form a discrete vortex system, of which components transverse to the flow direction overlap into the flow cross-section of the other part flow whereby to effect the desired mixing.

2. A method according to claim 1, wherein the vortex is generated by at least one curved surface disposed in said one fluid flow.

3. A method according to claim 1, wherein the vortex is initiated by at least one edge of a flat member or an edge of any other body.

4. A method according to claim 1, wherein the vortex is initiated by two edges of a delta-shaped insert element extending at an acute angle to one another.

5. Apparatus for mixing at least two fluid flows comprising at least two ducts joining one another and a vortex-generating element mounted at or adjacent the junction and so disposed in relation to one fluid flow path that, in operation, a discrete vortex system is generated which penetrates into the other flow path whereby to effect the required mixing.

6. Apparatus according to claim 5, wherein one said duct acts as a main duct and the other supply duct(s) is a supply duct connected laterally to the main duct.

7. Apparatus according to claim 6, wherein the element is mounted within the main duct in the zone of the opening of the supply duct and extends across the flow cross-section of both or all the fluid flows.

8. Apparatus according to claim 5, wherein one said element is in the flow cross-section of each fluid flow.

9. Apparatus according to claim 6, wherein a said element is mounted in the flow cross-section of the or each supply duct.

10. Apparatus according to claim 6, wherein the element is mounted in the main duct downstream of the opening(s) of the supply duct(s).

11. Apparatus according to claim 5, wherein the ducts extend parallel to one another upstream of the opening into a common main duct, at least one said element being mounted in the boundary flow area between the flow cross-sections of the adjacent fluid flows.

12. Apparatus according to claim 11, wherein the parallel ducts lie immediately adjacent to one another upstream of the main duct.

13. Apparatus according to claim 6, wherein the supply ducts extend concentrically with one another and there are arranged several said elements distributed in an annular arrangement of the closed boundary flow surface of the two flows.

14. Apparatus according to claim 13, wherein in the main duct downstream of the elements mounted in the boundary flow surfaces further vortex-generating elements are mounted with an orientation opposite to that of the first-mentioned elements.

15. Apparatus according to claim 6, comprising several supply ducts delivering parallel to one another into a common main duct in the delivery region of each supply duct one said element being mounted in the delivery region of each supply duct.

16. Apparatus according to claim 6, comprising several supply ducts delivering to the main duct upstream of reduction in the cross-section thereof, a respective said element being mounted in the boundary flow surface of the fluid flows of each supply duct flow.

17. Apparatus according to claim 6, comprising several supply ducts delivering laterally into the main duct, the supply ducts projecting by means of tubular sections into the main duct and the curved surfaces of these tube sections being constructed to generate effectively a said discrete vortex system.

18. Apparatus according to claim 17, wherein each tube section has a round or angular cross-section.

19. Apparatus according to claim 18, wherein each tube section is provided on its curved surface with at least one sharp-edged member.

20. Apparatus according to any one of claims 6 to 16, wherein each vortex generating element is constructed as a surface with an edge length, which has components extending both in the main flow direction and also transversely thereto.

21. Apparatus according to claim 20, wherein each element has edges symmetrical in relation to the main flow direction about a plane of symmetry.

22. Apparatus according to claim 21, wherein each element has a circular, elliptical, oval, parabolic or rhombic plan.

23. Apparatus according to claim 21, wherein the element is made of delta-shape with the tip pointing in the direction opposite to the main flow direction.

24. Apparatus according to any one of claims 20 to 23, wherein the or each element is profiled in cross-section to have a V shape and/or with angled edge.

25. A method of mixing fluid flows substantially as hereinbefore described with reference to the accompanying drawings.

26. Apparatus for mixing fluid flows substantially as hereinbefore described with reference to the accompanying drawings.

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